REFERENCE 190

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SUBJECT: Multiplication Measurements with Highly Enriched Uranium Metal Slabs

TO: Distribution

FROM: J. T. Mihalczo and J. J. Lynn

ABSTRACT

A series of neutron multiplication measurements with arrays of 1 by 8 by 10 in. slabs of 93.4% U^{235}-enriched uranium metal have been made to provide data from which safety criteria for the storage of these fissile units can be established. Each slab contained 22.9 kg of U^{235}. A maximum of 125 units was assembled. The arrays studied were cubic lattices of the units and were usually parallelepipedal in shape. Arrays were both unmoderated and Plexiglas-moderated and were surrounded in most cases by a 1-in.-thick Plexiglas reflector. The lattice densities (ratio of fissile unit volume to lattice cell volume) were between 0.023 and 0.06. Unmoderated lattices with a density of 0.06 would require 145 $\pm$ 5 units for criticality, while those with a density of 0.023 would require 350 $\pm$ 30 units. In lattices in which the fissile units are separated by 1 in. of Plexiglas, approximately 27 units would be required for a critical array with a lattice density of 0.06 and about 75 units for a density of 0.023. Distributing Foamglas (containing 2% boron) throughout a moderated array increased the critical number of fissile units by a factor of 5, while Styrofoam had a small effect.

NOTICE

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INTRODUCTION

Criteria for safe arrays of highly enriched uranium metal units are strongly dependent on the shape and weight of the units; consequently, the application of empirical relations established for one type of unit to another type is questionable. Several experimental investigations[1-4] performed at other laboratories have provided data from which safety criteria for arrays of spherical units of enriched uranium metal have been established.[5] In order to provide similar information for slab-type units, a series of neutron multiplication measurements with arrays of 1 by 8 by 10 in. slabs of uranium metal have been initiated at the ORNL Critical Experiments Facility. The metal is enriched to 93.4%, each slab containing 22.9 kg of U^{235}.

In the tests reported here the fissile units were assembled in cubic lattices surrounded in most cases by a 1-in.-thick reflector vault, Plexiglas on the top and sides and steel on the bottom. The lattice density (ratio of the fissile unit volume to the lattice cell volume) was between 0.023 and 0.06. Multiplication effects associated with variations in the reflector thickness, the source position, the lattice density, and the lattice shape were determined. The effect of introducing Plexiglas, Styrofoam, or Foamglas within the lattice was also studied.

I. DESCRIPTION OF ASSEMBLIES

The fissile units were assembled in Unistrut steel frameworks built on a "split" table which has a movable half and a fixed half. Three frameworks were constructed, two in which the center-to-center spacing of the fissile units was 12 in. and one with a spacing of 15 in. The two frameworks with the 12-in. spacing were capable of holding a 3 by 3 by 5 unit array and a 5 by 9 by 5 unit array, respectively, while the framework with the 15-in. spacing could hold a 5 by 5 by 5 unit array. A modification of one framework allowed lattices with an 11-in. center-to-center spacing to be assembled also. The two halves of one array of fissile units surrounded by Plexiglas are shown in Fig. 1.

Contamination and handling problems were reduced by placing the fissile units in 0.005-in.-thick plastic bags and bolting them into trays made of 1/16-in.-thick aluminum sheet. The aluminum trays were in turn placed in the

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1. E. C. Mallary et al., "Safety Tests for the Storage of Fissile Units," LA-1875 (1955).
2. C. L. Schuske, RFP-51 (1955)
3. C. L. Schuske, RFP-59 (1956)
4. C. L. Schuske, RFP-86 (1957)
5. C. L. Schuske, RFP-108 (1958)

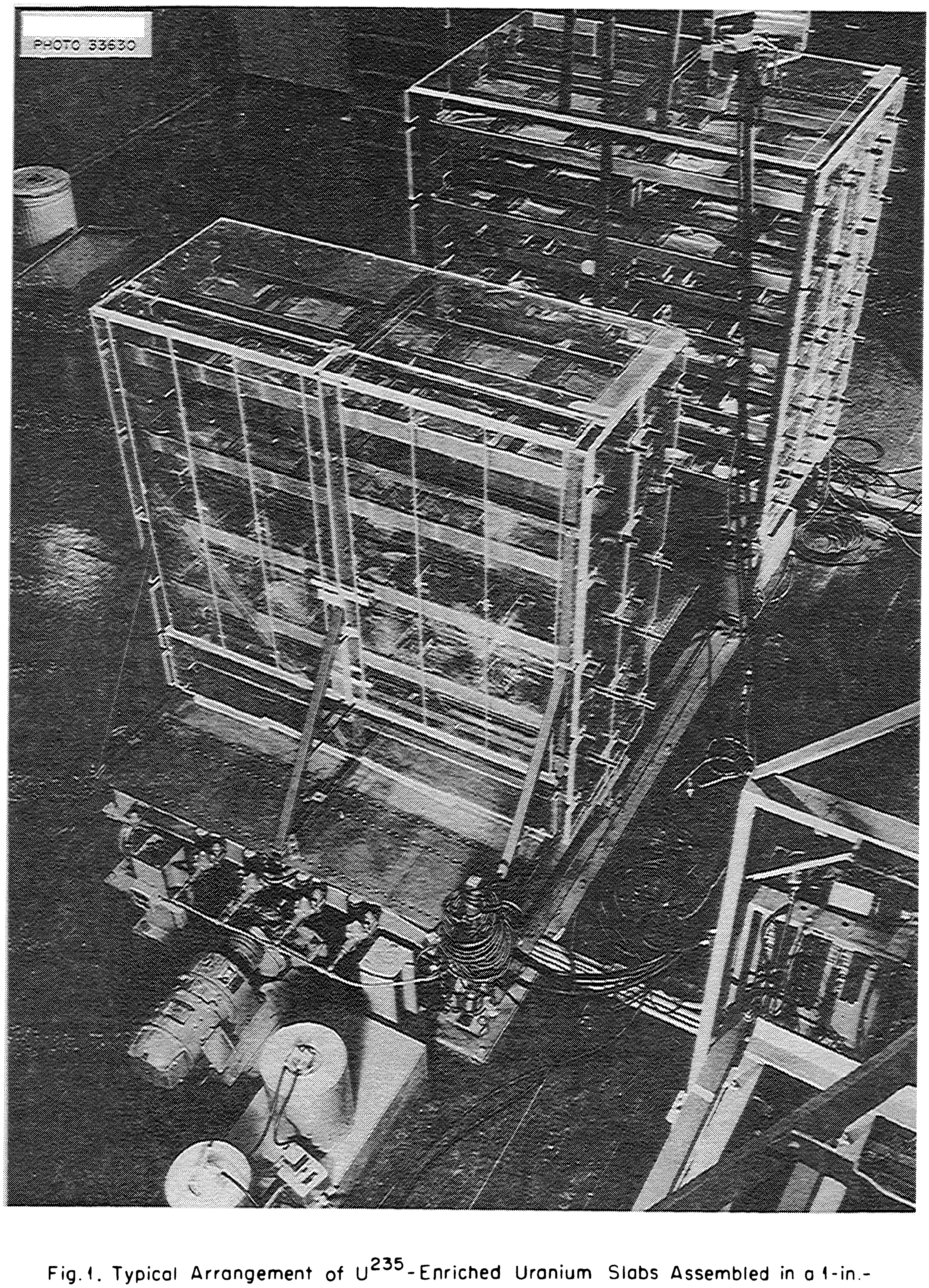

Fig. 1. Typical Arrangement of U^{235}-Enriched Uranium Slabs Assembled in a 1-in.-thick Plexiglas Vault on a Split Table (Movable Half of Assembly in Foreground).

framework as shown in Fig. 2, and a 1/32-in.-thick sheet of aluminum was suspended below each position in the lattice as a further restriction on the motion of the fissile units. The top and sides of the Plexiglas reflector vault were adjusted to fit the particular lattice being studied. (The Plexiglas could be fitted within the framework when the array was smaller than the framework.)

The numerical scheme used to designate lattice position is shown in Fig. 3. The order of loading the fissile units varied, depending on the size and shape of the lattice. The units were loaded either by hand or with the use of a crane while the table halves were 60 in. apart, the loading pattern being chosen so that it was never necessary to assemble more units by hand than were known to be subcritical.

The source used within the lattices was a 1-in.-OD by 5-in.-long Pu-Be source having a strength of $\sim 8 \times 10^6$ neutrons/sec.

Three BF_3-gas-filled counters (RCL Model 10500) placed in positions around the arrays were used to measure the neutron multiplication, and in some experiments a Hornyak button was placed within the lattice to detect fast neutrons. Variations in the performance of the counters were observed by placing the neutron source in a reproducible position and determining the counting rates. Background counts were taken with the neutron source removed from the room.

II. EXPERIMENTAL RESULTS

The experimental data presented in this section are reported in terms of self-multiplication, multiplication, or cross-multiplication. The definitions of these terms for this series of tests are as follows:

Self-multiplication (M_s) - - Ratio of the neutron flux* produced with a neutron source and a single fissile unit (U^{235}) to the flux produced with the source and an identical non-fissile unit (U^{238}).

Multiplication (M_o) - - Ratio of the neutron flux produced with a neutron source and a configuration of U^{235} units to the flux produced with the source and a single U^{238} unit placed in the first loading position of the particular array being studied.

Cross-multiplication (M_x) - - Ratio of the neutron flux produced with a neutron source and a configuration of U^{235} units to the flux produced with the source and a single U^{235} unit placed in the first loading position of the particular array being studied.

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* In each case the observed neutron flux is corrected for background.

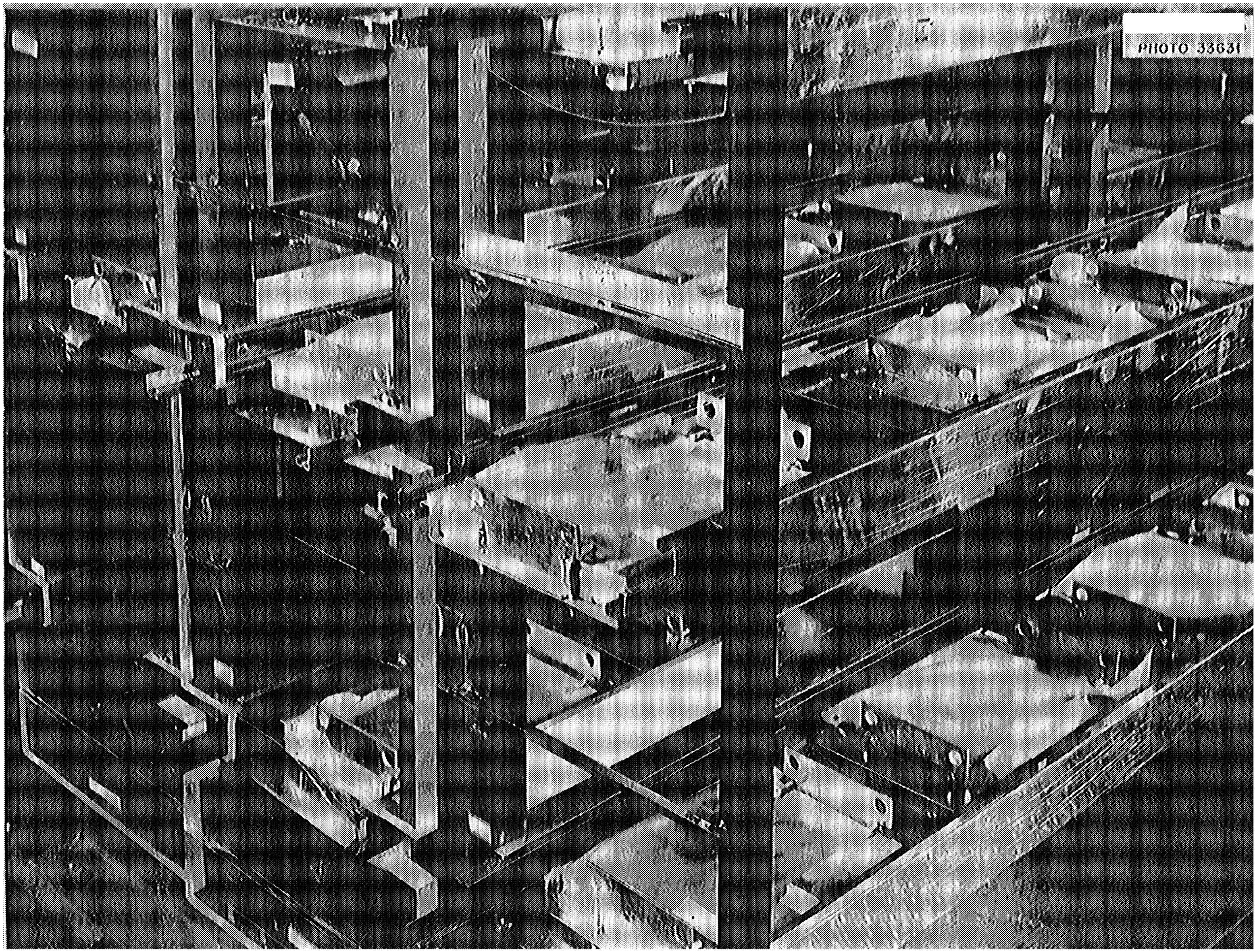

Fig. 2. Closeup of Individual Fissile Unit Cells in a Typical Assembly of U^{235}-Enriched Uranium Slabs.

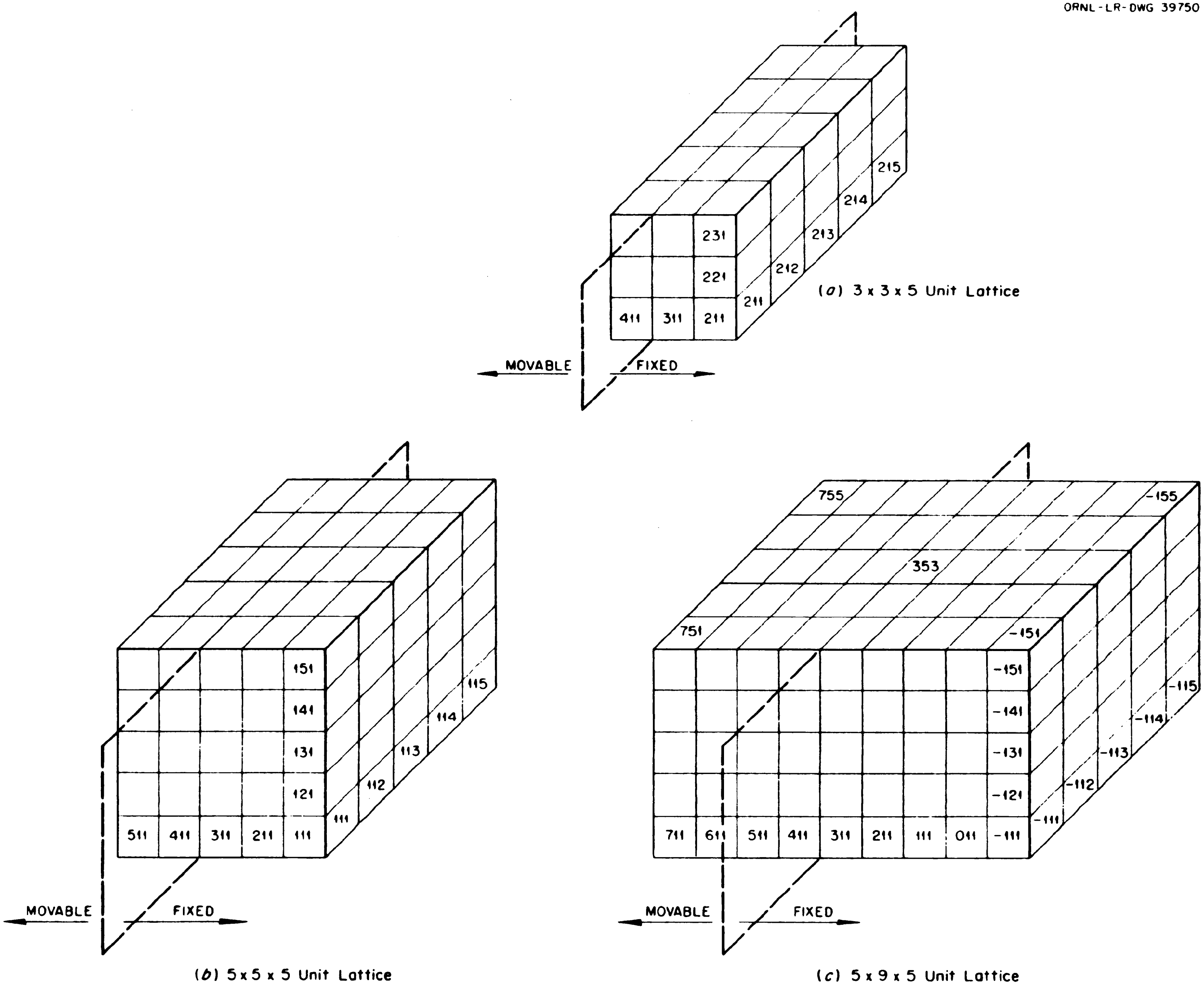

Fig. 3. Unit Cell Numbering System for Various Lattices of U^{235}-Enriched Uranium Slabs.

Self-Multiplication of Fissile Units

In order to determine the effect of neutrons reaching the detector without penetrating fissile material on the apparent source neutron multiplication, the self-multiplication of a single fissile unit with an internal neutron source was compared with the self-multiplication of a fissile unit with the source adjacent to one face. For the internal-source measurements, a 1/4-in.-OD by 1-in.-long Po-Be source (strength $\sim 10^5$ neutrons/sec) was placed in a 3/8-in.-dia by 5-in.-deep hole located in the center of a 1 by 8 in. face of the unit. The self-multiplication of the fissile unit with the external source was 1.4, as compared to 1.5 with the internal source. (The positions of the three counters during these measurements are shown in Table A-1 in Appendix A.)

The self-multiplication of a fissile unit in a plastic bag differed from that of a fissile unit wrapped in a 2-mil-thick aluminum foil by less than 1%. Since the moderating effect of aluminum is small compared to that of hydrogen, these results indicate that the plastic covers on the fissile units affect the multiplication of a lattice of fissile units only slightly.

Effect of Reflector Thickness

The effect of varying the thickness of the side and top reflectors on arrays of fissile units was investigated with several lattices contained in a reflector vault with inside dimensions of 3 by 3 by 5 ft. A 12-in. center-to-center separation of fissile units was used in each case. (The positions of the counters for these measurements are shown in Table A-2.) Figure 4 and Tables A-3 and A-4 in Appendix A show the effect on the reciprocal multiplication of increasing the side and top reflector thickness from 1 to 4 in. For a 3 by 3 by 5 unit lattice, adding 3 in. of paraffin to the 1 in. of Plexiglas on the sides and top of the reflector vault increased the neutron multiplication by a factor of 2.

Plots of the cross-multiplication of various arrays for three reflector conditions are shown in Fig. 5. Comparing the two lower curves at the 27-unit point indicates that removing the 1-in.-thick top and side reflector from a 3 by 3 by 3 unit configuration reduces the neutron multiplication by a factor of 1.2.

Effect of Lattice Density

The effect of the lattice density on the neutron multiplication was studied with lattices which had 11-, 12-, and 15-in. center-to-center separations and were assembled in cubical vaults having 55-, 60-, and 75-in. inside dimensions, respectively. The counter positions for these measurements are given in Table A-5 in Appendix A, and the reciprocal multiplications for the various arrays are shown in Fig. 6 and Table A-6. The effect of variations in the lattice density of arrays of Plexiglas-moderated fissile units is shown in Fig. 7, which is discussed further in the paragraph below.

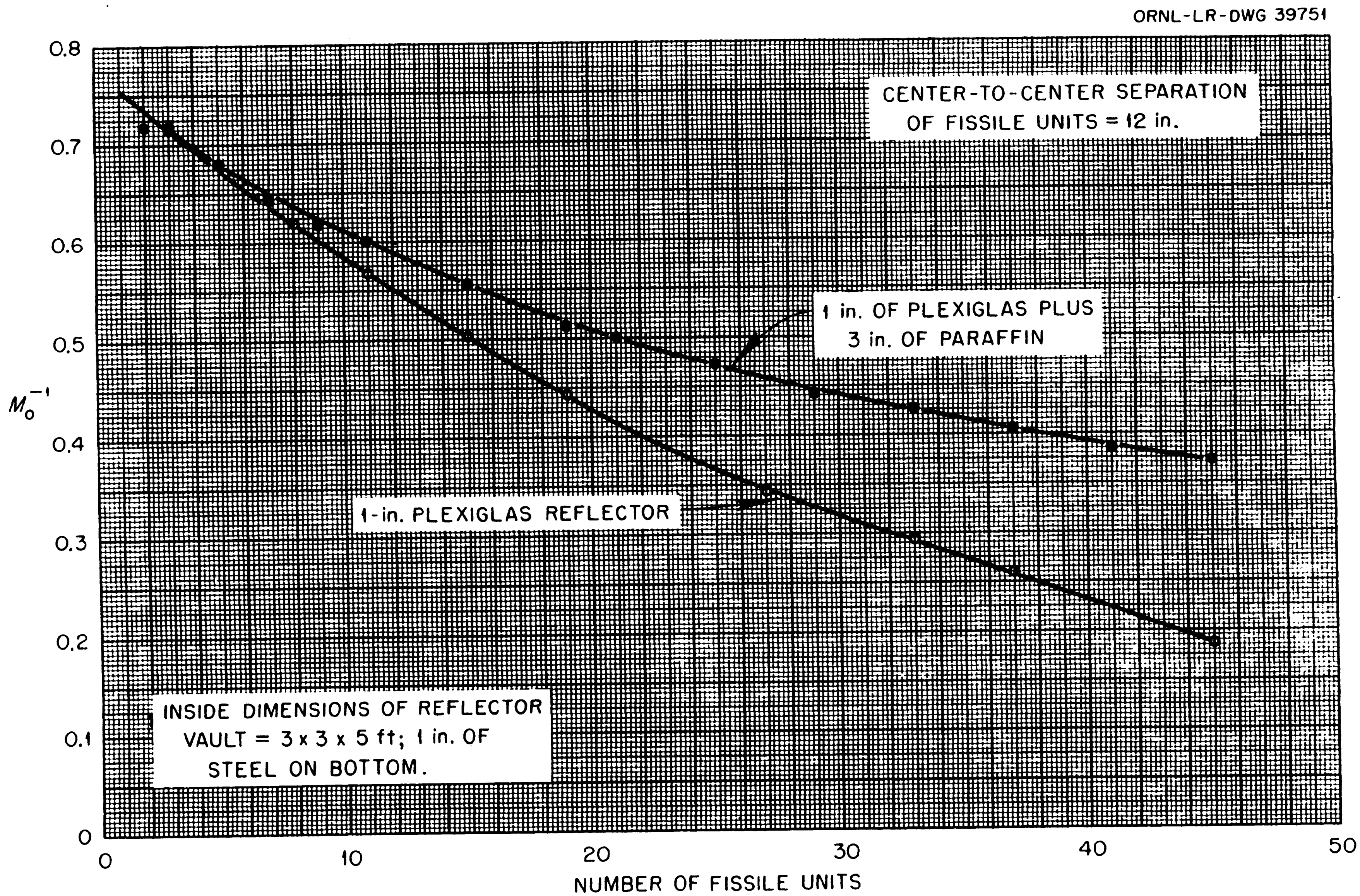

Fig. 4. Reciprocal Multiplication of Fissile-Unit Arrays Having Top and Side Reflector Thicknesses of 1 and 4 in.

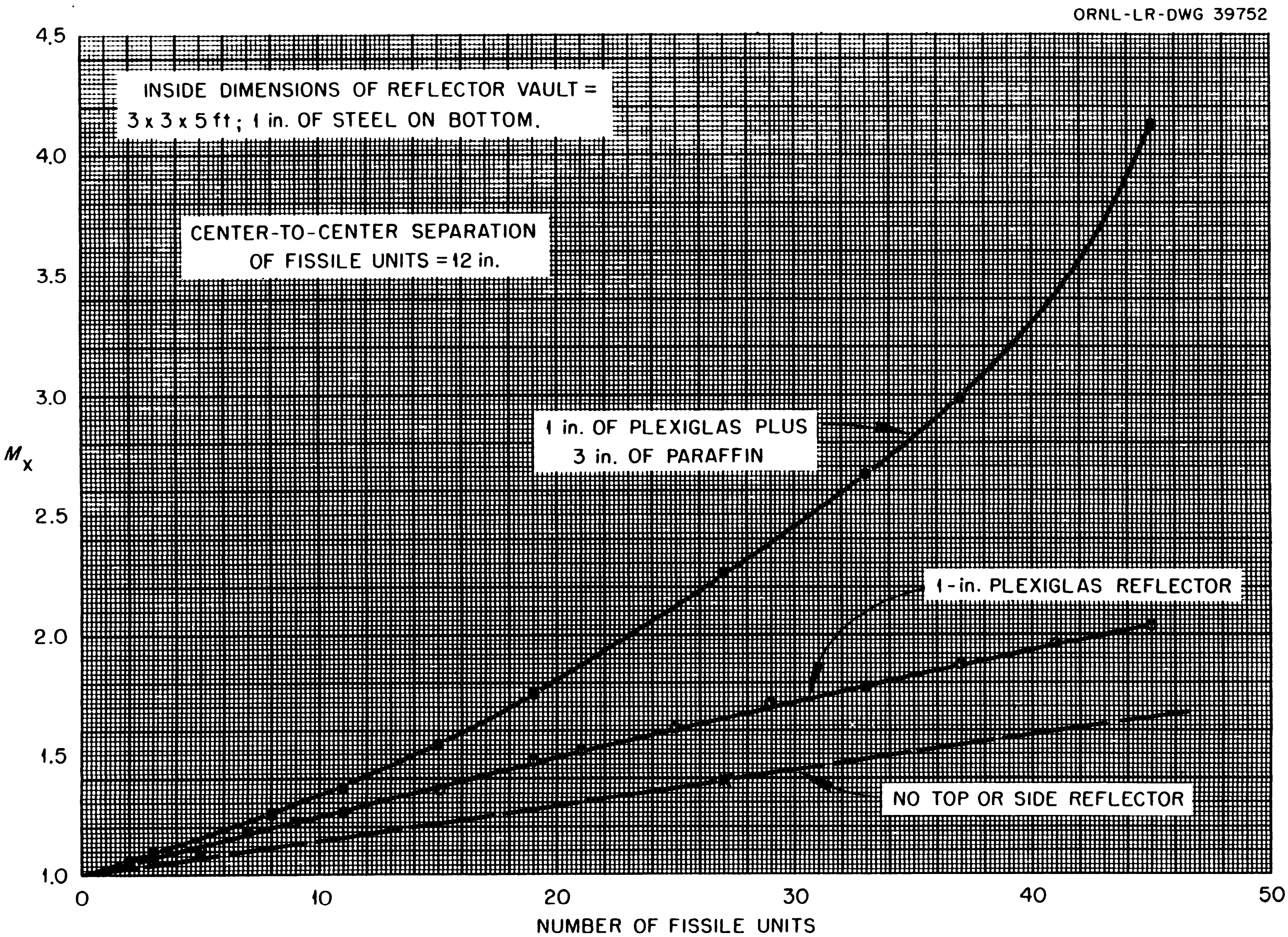

Fig. 5. Cross Multiplication of Fissile-Unit Arrays Having Top and Side Reflector Thicknesses of 0, 1, and 4 in.

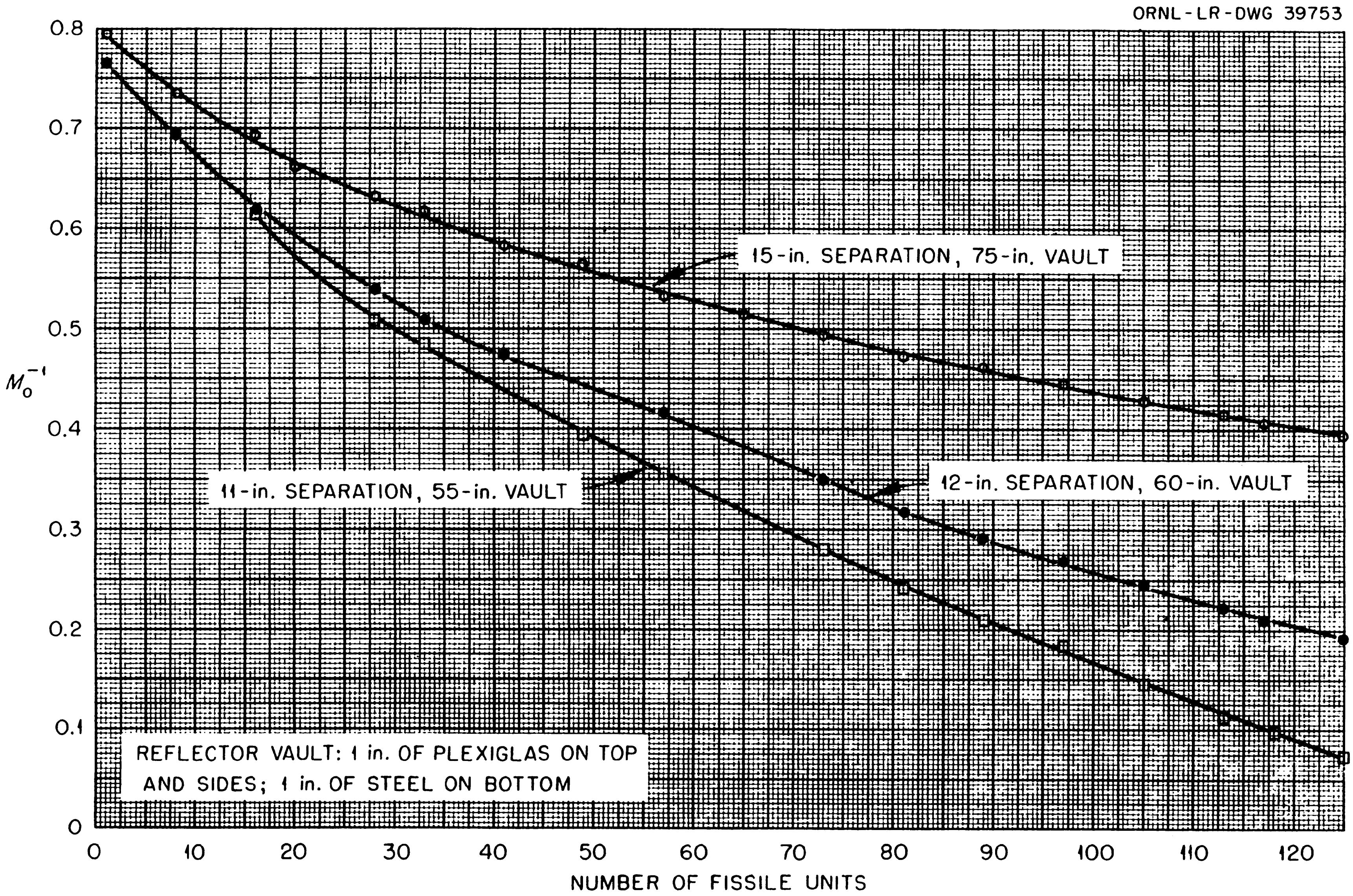

Fig. 6. Reciprocal Multiplication of Arrays of Unmoderated Fissile Units with 11-, 12-, and 15-in. Center-to-Center Separations.

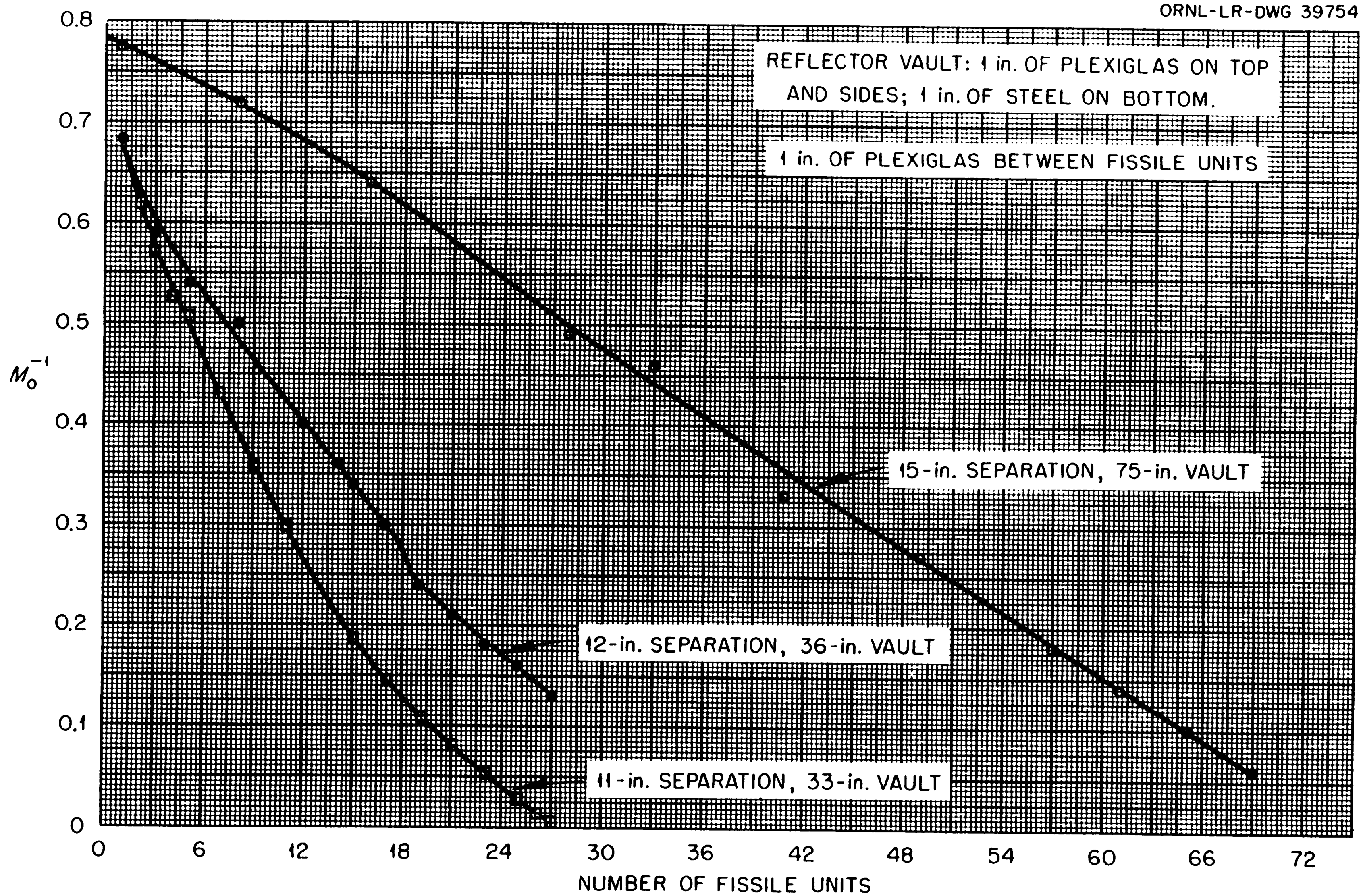

Fig. 7. Reciprocal Multiplication of Arrays of Plexiglas-Moderated Fissile Units with 11-, 12-, and 15-in. Center-to-Center Separations.

Effect of Plexiglas, Styrofoam,* and Foamglas** Separating Fissile Units

Previous experiments[4] in which the thickness of Plexiglas at the boundaries of unit cells was varied indicated that a 1-in.-thick layer gives maximum neutron multiplication. This plastic may be thought of as constituting a 0.5-in.-thick Plexiglas cell wall surrounding each fissile unit. More than 1 in. of Plexiglas reduces the neutron interaction between fissile units.

In order to investigate the effect of a 1-in.-thick Plexiglas moderator as a function of the lattice density, the neutron multiplication of moderated arrays of fissile units with 11-, 12-, and 15-in. center-to-center separations was observed. The positions of the counters for these measurements are given in Table A-7 in Appendix A, and the reciprocal multiplications are shown in Figs. 7 and 8 and Table A-8.

The effect of inserting Styrofoam and Foamglas (the latter containing 2% boron) into the unit cell of a Plexiglas-moderated lattice was also studied. In this case the fissile-unit center-to-center separation distance was 12 in., and the Styrofoam and Foamglas inserted into the unit cell occupied 70% of the total volume of the cell, assuming, as mentioned above, that the unit cell wall consisted of 0.5 in. of Plexiglas. The counter positions for these measurements were as shown in Table A-7. The neutron cross-multiplications of the arrays are given in Fig. 9 and Table A-9.

Effect of Source Position

In addition to showing the effect of a Plexiglas moderator, the curves in Fig. 8 show the dependence of the reciprocal multiplication on the source position. These curves indicate that the multiplication is not independent of the source position until the higher multiplication values are reached.

Effect of Lattice Geometry

The dependence of the neutron multiplication of an assembly on the manner in which it is assembled was studied by comparing the reciprocal multiplications of three different arrays as they approached their final dimensions of 3 by 3 by 9 units, 3 by 5 by 8 units, and 5 by 5 by 5 units, respectively. The counter positions for the first two lattices are given in Table A-10, while those for the third lattice are given in Table A-5. The loading orders and reciprocal multiplications of the 3 by 3 by 9 unit array and the 3 by 5 by 8 unit array are shown in Table A-11, and those of the 5 by 5 by 5 unit array are given in Table A-6. The reciprocal multiplication of all three arrays are plotted in Table 10.

* Styrofoam, $C_6H_5\,CH{:}CH_2$; $\rho = 0.024$ g/cc.
** Foamglas; $\rho = 0.141$ g/cc.

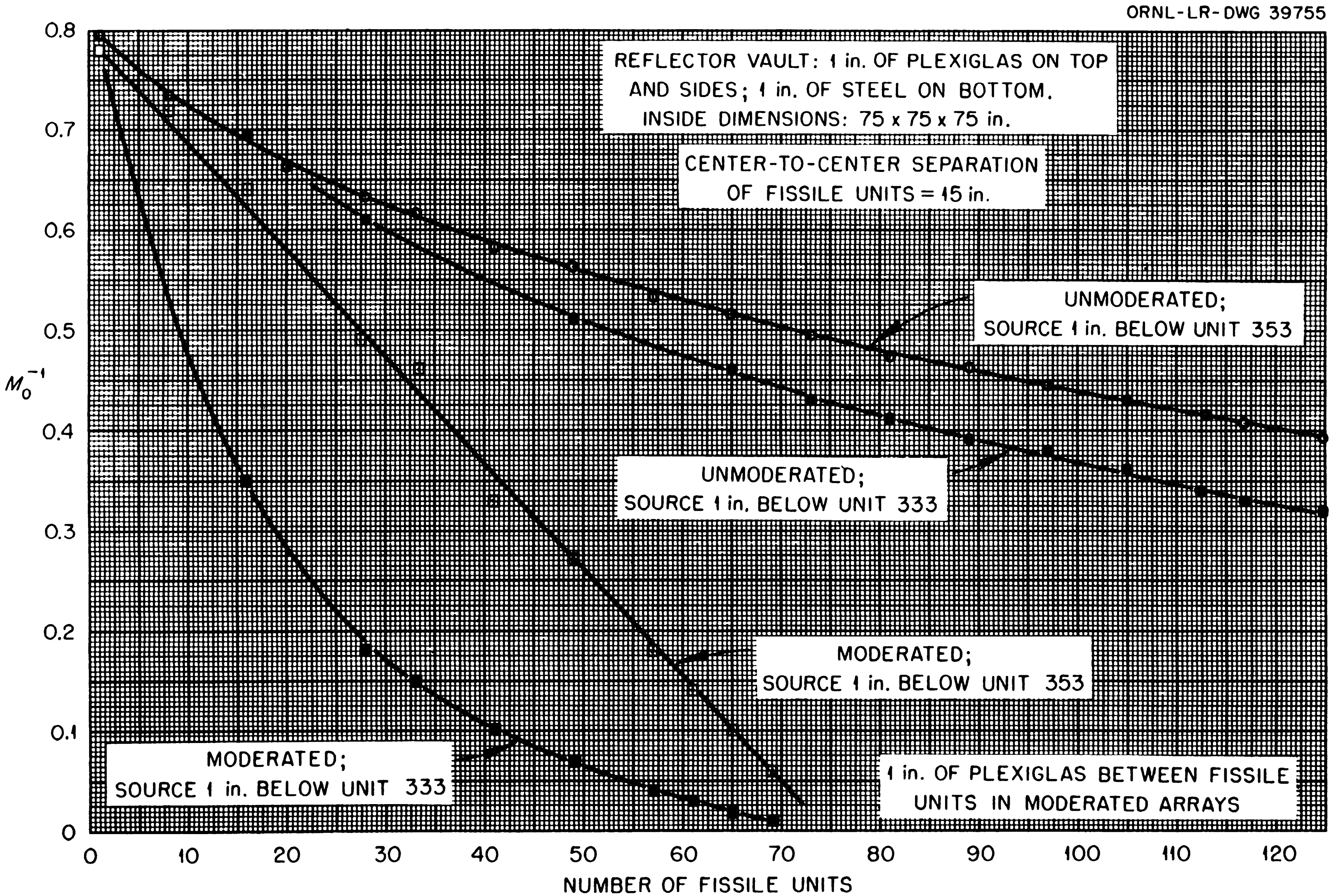

Fig. 8. Reciprocal Multiplication of Moderated and Unmoderated Fissile-Unit Arrays with Two Different Source Positions.

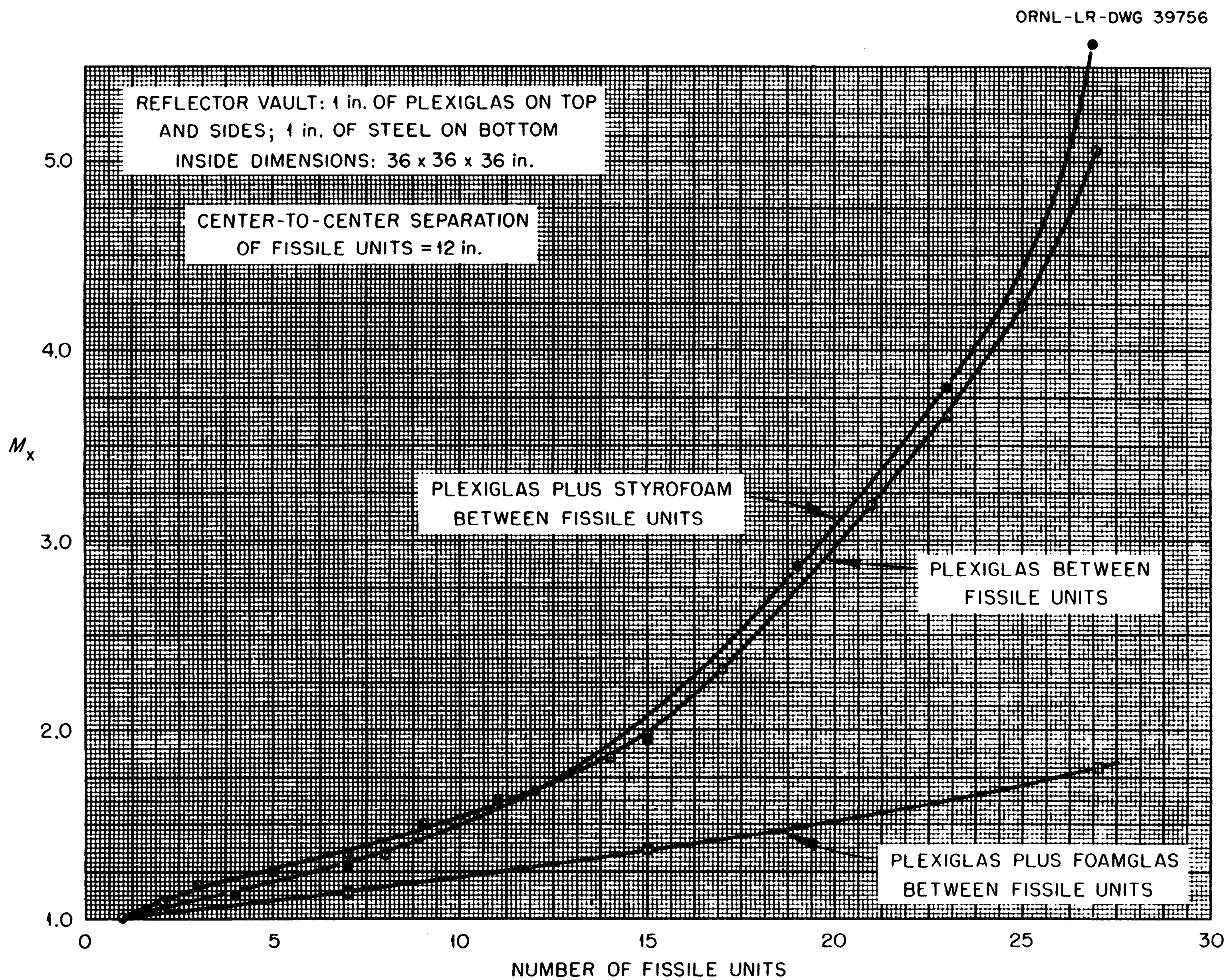

Fig. 9. Cross Multiplication of Arrays of Fissile Units Separated by Plexiglas Alone, Plexiglas and Styrofoam, or Plexiglas and Foamglas.

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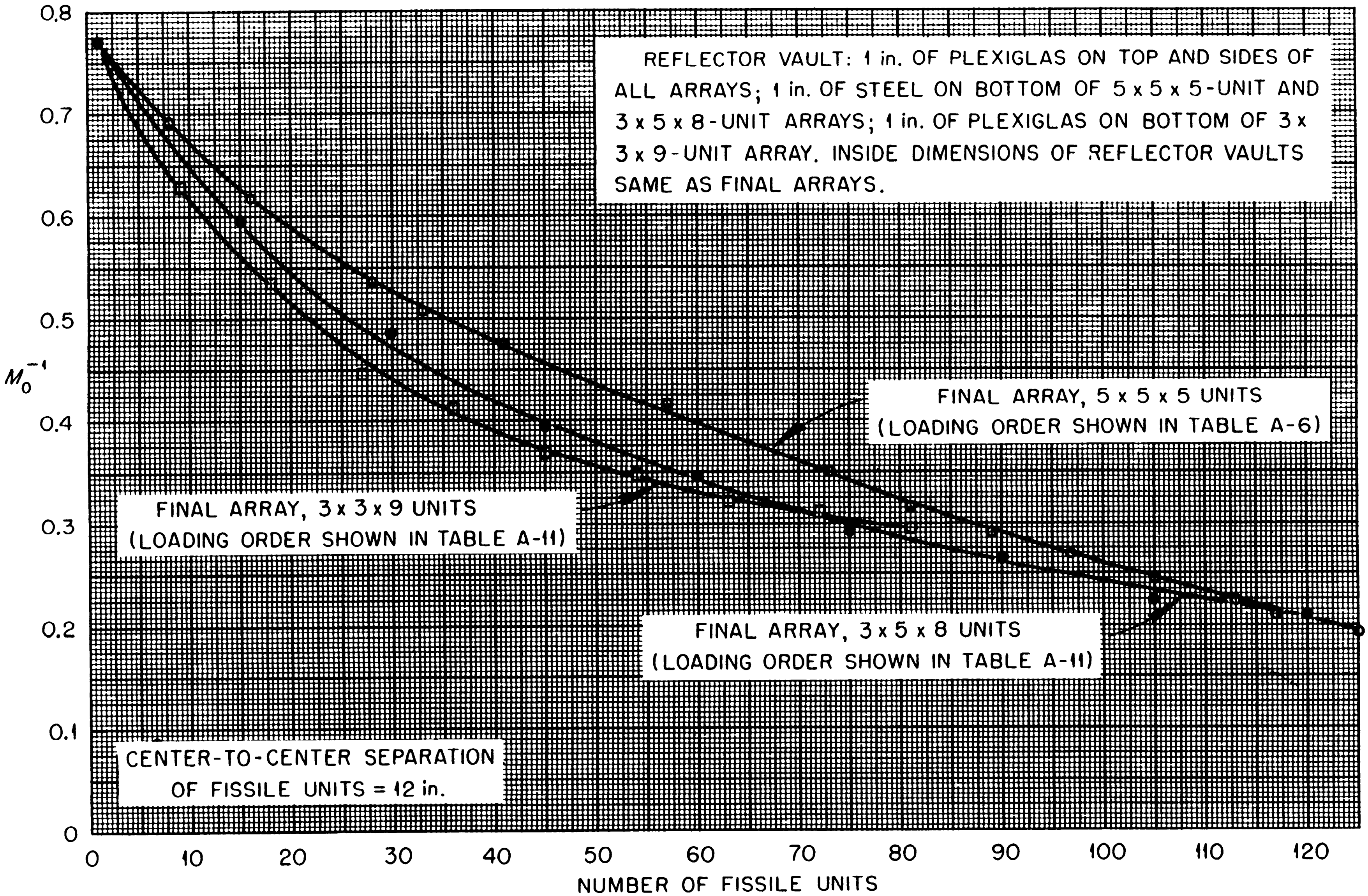

Fig. 10. Reciprocal Multiplication of Three Fissile-Unit Arrays Having Different Loading Orders (i.e., Different Geometries).

III. SUMMARY

The number of fissile units required for each lattice to become critical can be estimated by linearly extrapolating the reciprocal multiplication curve for the lattice to zero. The results of these extrapolations are shown by the open circles on Figs. 11 through 14.

Another method can be used to estimate the number of fissile units required for criticality of a particular type of array provided a good estimate of the number of units required for criticality at one lattice density is known. This method becomes apparent by a comparison of the plots in Figs. 11 to 14 which show the number of fissile units required for specific reciprocal multiplications in the various arrays as a function of the ratio of the fissile unit volume to lattice cell volume (lattice density). As the multiplication increases the lines become more nearly parallel. This indicates that the slope of the line representing critical arrays is the same as the slope of the lines for higher multiplications. Hence, if the number of fissile units required for criticality at one lattice density is known and if the number of fissile units required for high subcritical multiplications at other lattice densities is known, a line representing the critical number of fissile units for all lattice densities can be drawn. The latter method may provide a better extrapolation of low multiplication experiments.

An extrapolation of the inverse multiplication curve for unmoderated arrays with an 11-in. center-to-center spacing indicated that 145 ± 5 units would be required for criticality. The lattice density of an array with this spacing is 0.06. The critical line for all lattice densities is then obtained by plotting this point on Fig. 11(or on Fig. 12) and drawing a line that passes through the point and has the same slope as the line for the highest multiplication measured in the arrays. The same procedure is used to determine the critical lines for the moderated arrays (Figs. 13 and 14). Values taken from these critical lines are listed in Table 1.

When the extrapolations of the inverse multiplication curves for the 12- and 15-in. spacings are also plotted on Figs. 11 - 14, they fall close to the critical line. This procedure for establishing the critical line will be studied further in future experiments in which lattice densities greater than 0.5 will be investigated.

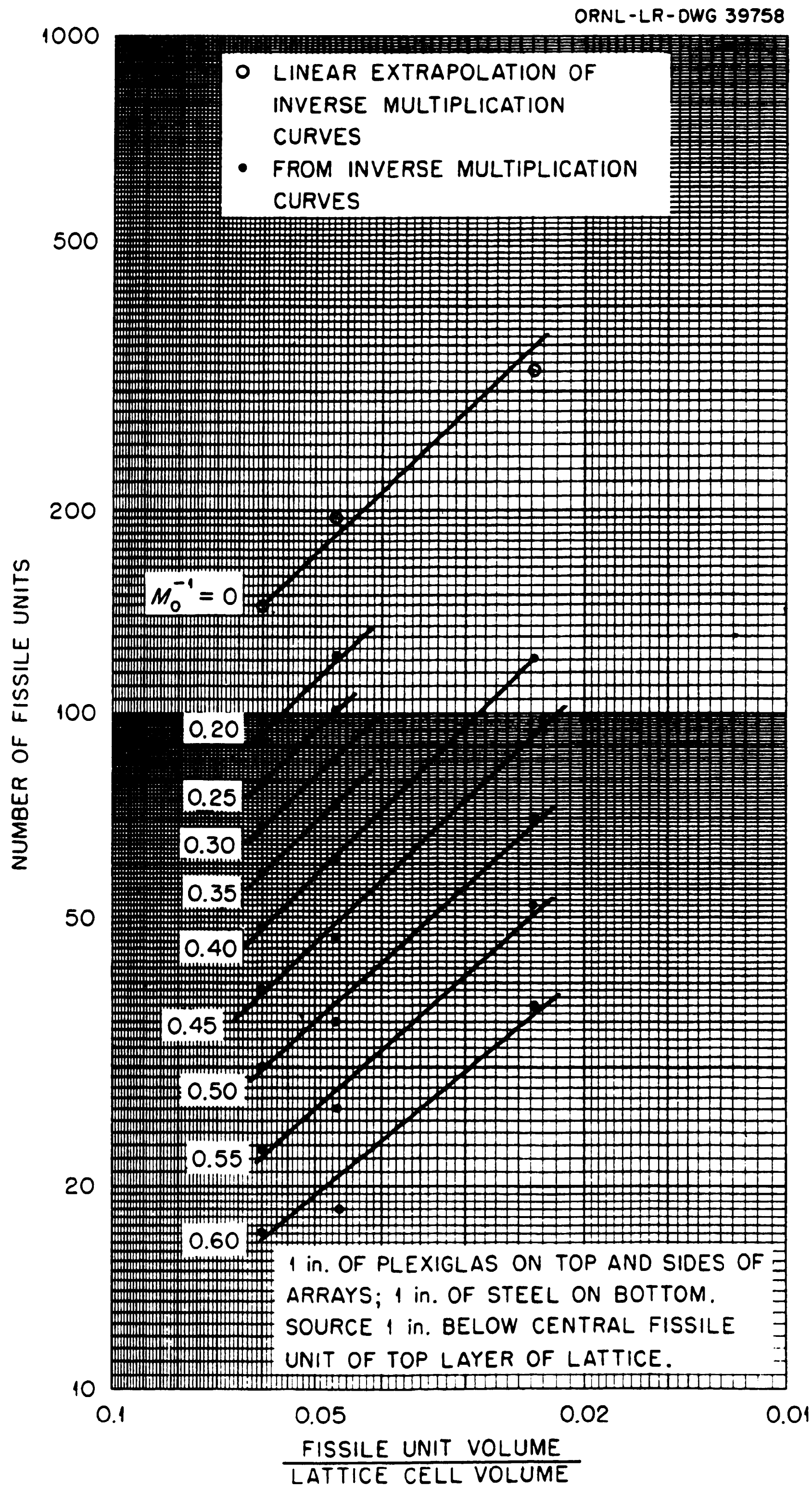

Fig. 11. Number of Unmoderated Fissile Units as a Function of the Ratio of Fissile Unit Volume to Lattice Cell Volume for Various Inverse Multiplications.

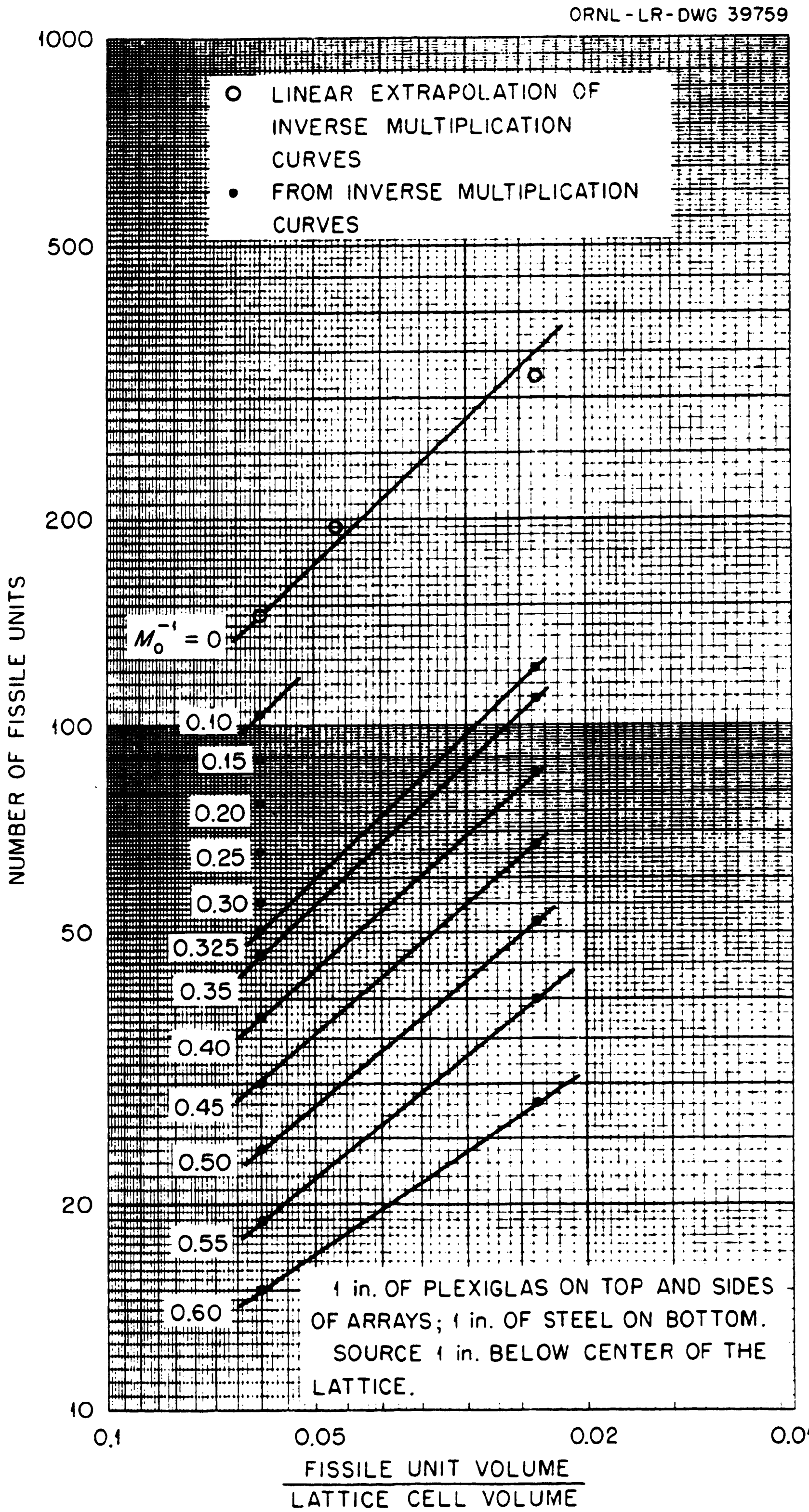

Fig. 12. Number of Unmoderated Fissile Units as a Function of the Ratio of Fissile Unit Volume to Lattice Cell Volume for Various Inverse Multiplications.

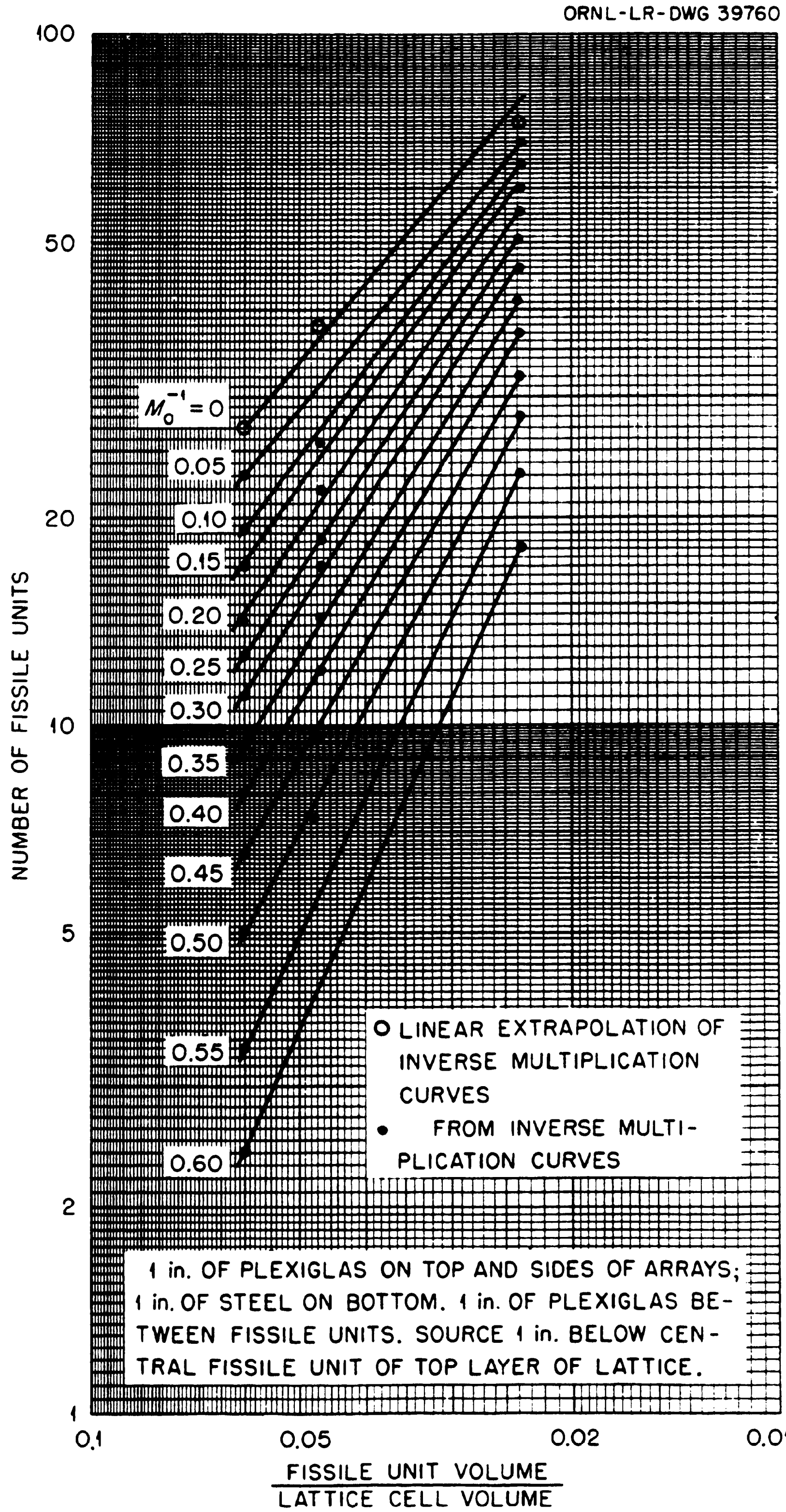

Fig. 13. Number of Plexiglas-Moderated Fissile Units as a Function of the Ratio of Fissile Unit Volume to Lattice Cell Volume for Various Inverse Multiplications.

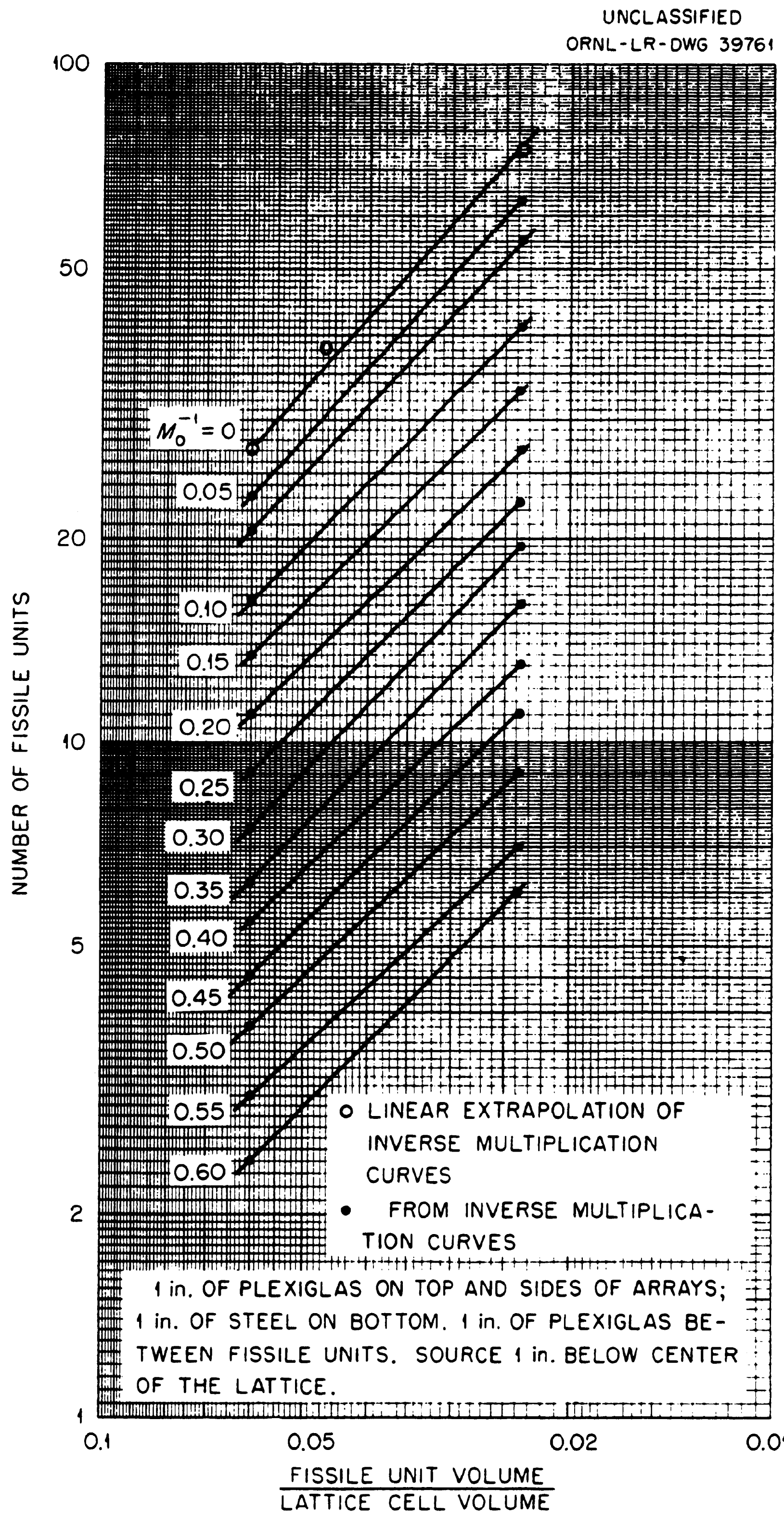

Fig. 14. Number of Plexiglas-Moderated Fissile Units as a Function of the Ratio of Fissile Unit Volume to Lattice Cell Volume for Various Inverse Multiplications.

Table 1. Estimated Number of Fissile Units Required for Critical Lattices in 1-in.-Thick Reflector Vaults

Center-to-Center Separation of Fissile Units (in.)	Number of Fissile Units			
	Unmoderated Lattice	Plexiglas[a] Between Fissile Units	Plexiglas[a] and Styrofoam[b] Between Fissile Units	Plexiglas[a] and Foamglas[b] Between Fissile Units
15	350 ± 30	75^{+5}_{-2}		
12	185 ± 10	36^{+5}_{-2}	36^{+5}_{-2}	185 ± 30
11	145 ± 5 (c)	$27^{+0.5}_{-0}$ (c)		

a. 1-in.-thick.
b. 70 vol% of unit cell.
c. Extrapolations of inverse multiplication curves.

Table A-1. BF_3 Counter Positions for Self-Multiplication Measurements

Counter No.	Counter Coordinates* x (in.)	y (in.)	z (in.)	Counter Axis Parallel to
1	45	-41	166	y axis
2	0	0	16	y axis
3	0	30	0	x axis

*x, y, z = 0 at center of fissile unit; 8 by 10 in. face of fissile unit in x, y plane with the 10-in. dimension parallel to the y axis.

Table A-2. BF_3 Counter Positions for Fissile Unit Arrays Having Various Reflector Thicknesses

Counter No.	Counter Coordinates* x (in.)	y (in.)	z (in.)	Counter Axis Parallel to
1	45	-41	166	y axis
2	-4	0	57	y axis
3	51	22	84	x axis

*x, y, z = 0 at center of lattice cell no. 323; 8 by 10 in. faces of fissile units in x, y planes with the 10-in. dimension parallel to the y axis.

Table A-3. Reciprocal Multiplication of Arrays of Fissile Units Assembled on 12-in. Centers in a Vault with 1-in.-Thick Sides and Top[a]

Number of Units	Lattice Loading Order[b]	$1/M_0$
1	333	0.76
2[c]	323	0.72
3	313	0.72
5	223, 423	0.68
7	322, 324	0.64
9	233, 413	0.62
11	213, 433	0.60
15	222, 224, 422, 424	0.56
19	314, 312, 334, 332	0.51
21	321, 325	0.50
25	212, 232, 414, 434	0.47
29	214, 234, 412, 432	0.44
33	311, 315, 331, 335	0.43
37	221, 225, 421, 425	0.41
41	215, 235, 411, 431	0.38
45	211, 231, 415, 435	0.37

a. Inside dimensions of vault = 3 x 3 x 5 ft.
b. Source position was 1 in. below center of fissile unit 333.
c. Unit previously placed in position 333 plus unit in position 323.

Table A-4. Reciprocal Multiplication of Arrays of Fissile Units Assembled on 12-in. Centers in a Vault with 4-in.-Thick Sides and Top[a]

Number of Units	Lattice Loading Order[b]	$1/M_o$
1	333	0.77
3	313, 323	0.71
8	322, 324, 413, 423, 433	0.62
11	213, 223, 233	0.57
15	222, 224, 422, 424	0.50
19	312, 314, 332, 334	0.44
27	212, 214, 232, 234, 412, 414, 432, 434	0.34
33	321, 325, 311, 315, 331, 335	0.29
37	225, 221, 425, 421	0.26
45	211, 231, 215, 415, 411 431, 235, 435	0.19

a. Vault wall consisted of 1 in. of Plexiglas and 3 in. of paraffin; inside dimensions of vault = 3 x 3 x 5 ft.

b. Source position was 1 in. below center of fissile unit 333.

Table A-5. BF_3 Counter Positions for Unmoderated Arrays of Fissile Units Assembled on 11-, 12- and 15-in. Centers

Center-to-Center Separation of Fissile Units (in.)	Counter[a]	Counter Coordinates[b]		
		x (in.)	y (in.)	z (in.)
15	1	107	-49	171
	2	-2	0	73
	3	-68	0	27
12	1	105	-55	177
	2	-4	0	56
	3	-70	-6	35
11	1	104	-58	180
	2	-5	0	63
	3	-71	-9	38

a. All counter axes parallel to y axis.
b. x, y, z = 0 at center of fissile unit in lattice cell no. 333; 8 by 10 in. faces of fissile units in x,y planes with 10-in. dimension parallel to y axis for 12- and 15-in. spacings and parallel to x axis for 11-in. spacing.

Table A-6. Reciprocal Multiplication of Unmoderated Arrays of Fissile Units Assembled on 11-, 12-, and 15-in. Centers

Number of Units	Lattice Loading Order	$1/M_o$ 11-in. Spacing a	11-in. Spacing b	12-in. Spacing a	12-in. Spacing b	15-in. Spacing a	15-in. Spacing b
1	353	0.82		0.76		0.79	
8	333,323,233,433, 334,332,343	0.71		0.69		0.74	
16	443,423,243,223, 432,343,232,234	0.62	0.59	0.62		0.69	
20	322,324,342,344					0.66	0.66
28	222,224,242,244, 422,424,442,444	0.51	0.54	0.54		0.63	0.61
33	313,331,335,133, 533	0.49		0.51		0.62	
41	352,354,253,453, 312,314,213,413			0.47		0.58	
49	235,325,345,435, 231,321,341,431	0.40	0.33			0.56	0.51
57	123,143,132,134, 523,543,532,534	0.36		0.42		0.53	
65	412,414,252,254					0.52	0.46
73	221,225,421,425	0.28	0.22	0.35		0.47	0.43
81	122,124,142,144, 522,524,542,544	0.24	0.18	0.32		0.47	0.41
89	113,153,513,553, 311,315,351,355	0.21	0.15	0.29		0.46	0.39
97	131,135,141,125, 531,535,521,545	0.18	0.13	0.27		0.45	0.38
105	525,541,411,121, 251,145,255,415	0.14		0.24		0.43	0.36
113	451,455,211,215, 112,114,552,554	0.11		0.22		0.42	0.34
117	152,154,512,516	0.10		0.21		0.41	0.33
125	111,555,151,511, 115,551,515,155	0.07	0.05	0.19	0.13	0.40	0.32

a. Source position was 1 in. below fissile unit 353.
b. Source position was 1 in. below fissile unit 333.

Table A-7. BF_3 Counter Positions for Arrays of Fissile Units Assembled on 11-, 12-, and 15-in. Centers and Separated by Plexiglas, Plexiglas and Styrofoam, or Plexiglas and Foamglas

Center-to-Center Separation of Fissile Units (in.)	Counter[a]	Origin of Coordinates	Counter Coordinates[b] x (in.)	y (in.)	z (in.)
15	1	At center of fissile unit 333	107	-49	171
	2		- 2	0	73
	3		-68	0	27
12	1	At center of fissile unit 323	45	-41	166
	2		- 4	0	57
	3		51	22	84
11	1	At center of fissile unit 342	104	-69	191
	2		- 5	0	52
	3		-71	-17	49

a. All counter axes parallel to y axis.

b. 8 by 10 in. faces of fissile units in x,y planes with 10-in. dimension parallel to y axis for 12- and 15-in. spacings and parallel to x axis for 11-in. spacing.

Table A-8. Reciprocal Multiplication of Plexiglas-Moderated[a] Arrays of Fissile Units Assembled on 11-, 12-, and 15-in. Centers

Number of Units	Lattice Loading Order: 11-in. Spacing	Lattice Loading Order: 12-in. Spacing	Lattice Loading Order: 15-in. Spacing	$1/M_o$: 11-in. Spacing, b	$1/M_o$: 11-in. Spacing, c	$1/M_o$: 12-in. Spacing, b	$1/M_o$: 15-in. Spacing, d	$1/M_o$: 15-in. Spacing, b
1	333	333	353	0.687		0.67	0.78	
2		433				0.62		
3	323, 324	323		0.59		0.57		
4	313			0.53				
5	322	423, 313		0.51		0.54		
7	223, 423			0.43	0.32			
8		413, 213, 223	333, 323, 233, 433, 334, 332, 343			0.50	0.72	0.73
9	213, 433			0.36	0.26			
11	233, 413			0.30				
12		424, 423, 324, 233				0.40		
13	314, 332			0.24				
14		322, 222				0.36		
15	312, 334	224		0.19	0.12	0.34		
16			443, 423, 243, 223, 432, 343, 232, 234				0.64	0.35
17	222, 424	332, 314		0.15		0.30		
19	422, 224	312, 334		0.11	0.06	0.24		
21	212, 434	212, 434		0.08	0.04	0.21		
23	432, 214	412, 234		0.05	0.03	0.18		
25	412, 234	432, 214		0.027		0.16		
26	414			0.014				
27	232	414, 232		0.006		0.13		
28			222, 224, 242, 244, 422, 424, 442, 444				0.49	0.18
33			313, 331, 335, 133, 533				0.46	0.15
41			352, 354, 253, 453, 312, 314, 213, 413				0.33	0.10
49			235, 325, 345, 435, 231, 321, 341, 431				0.27	0.07
57			123, 143, 132, 134, 523, 543, 532, 534				0.18	0.04
61			212, 214, 452, 454				0.14	0.03
65			412, 414, 252, 254				0.10	0.02
69			241, 245, 441, 445				0.06	0.01

a. 1 in. of Plexiglas between fissile units.
b. Source position was 1 in. below fissile unit 333.
c. Source position was 1 in. below fissile unit 323.
d. Source position was 1 in. below fissile unit 353.

Table A-9. Neutron Multiplication of Arrays of Fissile Units Assembled on 12-in. Centers and Separated by Plexiglas, Foamglas and Styrofoam

Number of Units	Lattice Loading Order[a]	$1/M_o$, Plexiglas[b] Between Fissile Units	M_x: Plexiglas Between Fissile Units	M_x: Plexiglas[b] and Styrofoam[c] Between Fissile Units	M_x: Plexiglas[b] and Foamglas[c] Between Fissile Units
1	333	0.67	1.0	1.0	1.0
2	433	0.62	1.09		
3	323	0.57	1.18		
5	423, 313	0.54	1.25		
8	413, 213, 223	0.50	1.34		
12	424, 422, 324, 233	0.40	1.68		
14	322, 222	0.36	1.85		
15	224	0.34	1.96	1.92	1.36
17	332, 314	0.30	2.32	2.86	
19	312, 334	0.24	2.84		
21	212, 434	0.21	3.18		
23	412, 234	0.18	3.66	3.8	
25	432, 214	0.16	4.2		
27	414, 232	0.13	5.06	5.65	1.81
Additional Points Obtained					
7	333, 323, 313, 322 324, 223, 423	0.47	1.33	1.28	1.13
9	333, 323, 313, 322, 324 223, 423, 213, 433	0.45	1.5		

a. Source position was 1 in. below fissile unit 333.

b. 1 in. thick.

c. 70 vol% of unit cell.

Table A-10. BF_3 Counter Positions for Arrays of Fissile Units Approaching 3 by 3 by 9 Units and 3 by 5 by 8 Units

			Counter Coordinates[b]		
Final Array	Counter[a]	Origin of Coordinates	x (in.)	y (in.)	x (in.)
3 x 3 x 9 units	1	At center of fissile unit 344	1.5	-67	165
	2		- 4	0	56
	3		-70	-18	23
3 x 5 x 8 units	1	At center of fissile unit 343	105	-55	165
	2		- 4	0	56
	3		-70	- 6	23

a. All counter axes parallel to y axis.

b. 8 by 10 in. faces of fissile units in x,y planes with 10-in. dimension parallel to y axis.

Table A-11. Reciprocal Multiplication of Arrays of Fissile Units Approaching 3 by 3 by 9 Units and 3 by 5 by 8 Units

	Lattice Loading Order		$1/M_o$	
Number of Units	Final Array, 3 x 3 x 9 Units[a]	Final Array, 3 x 5 x 8 Units[b]	Final Array, 3 x 3 x 9 Units	Final Array, 3 x 5 x 8 Units
1	354	354	0.77	0.76
9	333-335, 343-345, 353, 355		0.63	
15		351, 352, 353, 355, 341-345, 331-335		0.60
18	453-455, 443-445, 433-435		0.54	
27	253-255, 243-245, 233-235		0.47	
30		451-455, 441-445, 431-435		0.49
32	553-555, 543-545, 533-535		0.41	
45	153-155, 143-145, 133-135	251-255, 241-245, 231-235	0.37	0.39
54	653-655, 643-645, 633-635		0.35	
60		551-555, 541-545, 531-535		0.34
63	053-055, 043-045, 033-035		0.32	
72	753-755, 743, 745, 733-735		0.31	
75		151-155, 141-145, 131-135		0.29
81	-153, -154, -155 -143, -144, -145, -133, -134, -135		0.29	
90		651-655, 641-645, 631-635		0.26
105		051-055, 041-045, 031-035		0.22
120		751-755, 741-745, 731-735		0.21

a. Source position was 1 in. below fissile unit 354.
b. Source position was 1 in. bwloe fissile unit 353.

Appendix B

LIST OF FIGURES